REFLECTION AT LARGE DISTANCE FROM THE CENTRAL ENGINE IN SEYFERTS

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We consider the possibility that most of the reflection component, observed in the hard X-ray spectra of Seyfert galaxies, could be formed on an extended medium, at large distance from the central source of primary radiation (e.g. on a torus). Then, the reflector cannot respond to the rapid fluctuations of the primary source. The observed reflected flux is controlled by the time-averaged primary spectrum rather than the instantaneous (observed) one. We show that this effect strongly influence the spectral fits parameters derived under the assumption of a reflection component consistent with the primary radiation. We find that a pivoting primary power-law spectrum with a nearly constant Comptonised luminosity may account for the reported correlation between the reflection amplitude R and the spectral index Γ.

1. Introduction

In radio-quiet active galactic nuclei, large amounts of cold material are thought to reside at large distance from the central engine. In particular, the unified scheme (Antonucci 1993) postulates a large scale torus (with radius larger than 10^{16} cm). Such distant cold material (hereafter DCM) may imprint strong reflection features in the hard X-ray spectrum of Seyfert 1 galaxies (Ghisellini, Haardt & Matt 1994; Krolik, Madau & Życki 1994). It has been argued that the reflection produced by an irradiated torus would be sufficient to account for the typical observed reflection spectra, without need for reflecting material in the inner parts of the accretion flow (e.g. disc reflection).

In Compton thick Seyfert 2s, the observed reflection dominated spectra are generally interpreted by DCM reflection with the primary emission obscured presumably by the same outer material (e.g. Reynold *et al.*, 1994; Matt *et al.*, 2000).

In Seyfert 1s, the detection of a narrow iron line component (Lubinski & Zdziarski 2000) is also suggestive of reflection on DCM. Probably, the best evidence for significant reflection on DCM in a Seyfert 1, comes from the BeppoSax and RXTE observation of NGC4051 in a very low flux state. Both spectral and timing data were found consistent with the interpretation that the source had switched off, leaving only a spectrum of pure reflection from DCM at distances larger than 10^{17} cm (Guainazzi *et al.*1998, Uttley *et al.*1999).

The aim of this paper is to emphasize some observable effects introduced by DCM reflection and discuss these effects in the context of the reported R–Γ correlation (Zdziarski, Lubiñski & Smith 1999).

2. The measured reflection amplitude R

When analyzing the X-ray data, the possible contribution from DCM reflection is not considered a priori. The data are generally interpreted in the framework of reflection in the vicinity of the hard X-ray source, possibly on the accretion disc. Usually, in spectral fits, the shape of the reflection component is computed assuming that the *observed* primary spectrum illuminates an infinite disc (e.g. PEXRAV model in XPEC, Magdziarz & Zdziarski 1995). The normalization of the reflected spectrum is then tuned in order to fit the observed spectrum. The results of this fitting procedure provides the reflection amplitude R. R is normalized so that $R = 1$ in the case of an isotropic source above an infinite reflecting plane. R is often considered as an estimate of $\Omega/2\pi$ where Ω is the solid angle subtended by the reflector as seen from the isotropic X-ray source.

3. Effects of a distant reflector

Obviously, any contribution from a remote structure leads to an increase of R and may lead to an overestimate of the disc reflection. This may explain the very large R coefficients ~ 2, measured in some Seyfert 1s, which are difficult to reconcile with disc reflection (see however Beloborodov 1999; Malzac, Beloborodov & Poutanen 1999). In addition, the nuclei of Seyfert galaxies are known to harbor a significant variability on very short time scale (< 1 day, see e.g. Nicastro *et al.*2000; Nandra *et al.*2000; Chiang *et al.*2000). Due to its extended structure the remote reflector cannot respond to the rapid fluctuations of the primary X-ray flux. *The reflected component from the DCM is thus likely to correspond to the time-averaged incident flux rather than to the instantaneous (i.e. observed) one.* Thus flux changes may induce a significant variation in the R value derived from the spectral fits. A flux lower than the average enhances the apparent reflection, on the other hand, a larger flux may reduce R down to zero. Then values of R as low or large as required by the data can be easily produced. This kind of effect, when important, makes the geometrical interpretation of R extremely misleading. *Trying to disentangle the temporal and geometrical effects is extremely difficult* and requires very long observations with time resolved spectral analysis.

4. Is distant reflection consistent with a R-Γ correlation ?

A significant contribution from a remote reflector seems, at first sight, in contradiction with the reported correlation between R and the spectral slope Γ (Zdziarski, Lubiñski & Smith, 1999). This correlation is observed in sample of sources as well as in the time evolution of individual sources. The measured R tends to be larger in softer sources. The usual interpretation of the correlation invoke the feedback from reprocessed radiation emitted by the reflector itself. It thus absolutely requires a close reflector. In the context of DCM reflection, it is difficult to understand why the reflection contribution from DCM should be more important in objects with softer spectra.

It has been however suggested by Nandra *et al.*(2000) that, in the case of reflection on DCM, *rapid spectral changes of the primary emission can strongly affect the measured R. The R vs* Γ *relation then depends on the specific spectral variability mode of the sources.* It may possibly produce a correlation between R and Γ.

In several sources such as NGC5548 (Nicastro *et al.*2000, Petrucci *et al.*2000), the short timescale variability is consistent with fluctuations of the X-ray spectral slope with a nearly constant comptonised luminosity, i.e. the spectrum is mainly pivoting. This can happen for example if the UV luminosity entering the hot Comptonising plasma changes with a constant heating rate in the hot plasma (e.g. Malzac & Jourdain 2000). In the following we investigate the R vs Γ dependence for this variability mode.

5. Modeling method

We assume that the time average primary spectrum seen by the DCM can be represented by a power law with a photon index $\Gamma = 1.9$ and an exponential cut-off at 200 keV. Neglecting any disc reflection, we further assume that the DCM geometry is such that the time averaged primary spectrum yield a reflection coefficient $R = 0.5$. As a first order approximation, the shape of the reflection spectrum is computed using the PEXRAV procedure, i.e. assuming a slab reflector. Fixing the cut-off energy at 200 keV, we produced a set of instantaneous primary spectra for several photon indices Γ spanning the observed range 1.4–2.2. The 1 keV normalization was tuned so that the 0.01–100 keV luminosity was identical for all spectra. We then added the reflection component, produced as described above, to these instantaneous spectra, and fitted the resulting spectra with PEXRAV in the 2-30 keV range. We also fitted the simulated spectra in the 2–100 keV range. In both energy ranges, the derived best fit parameters were very similar. Similarly, we estimated the effects of variability on the measured equivalent width (EW) of the iron line. We modeled the intrinsic iron line by a Gaussian with an intrinsic width $\sigma = 0.1$ eV and a total flux normalized so that the EW is 50 eV for the $\Gamma = 1.9$ time averaged primary spectra (i.e. roughly consistent with a reflection amplitude $R = 0.5$; George & Fabian 1991).

6. Results

6.1. The R–Γ correlation

The R-Γ relation resulting from our modeling procedure is shown in Fig. 1. The assumed variability mode (i.e. variability at constant flux) results in a spectrum pivoting at energies lower than 10 keV i.e. below the energy range were most of reflection is produced. Thus, when the

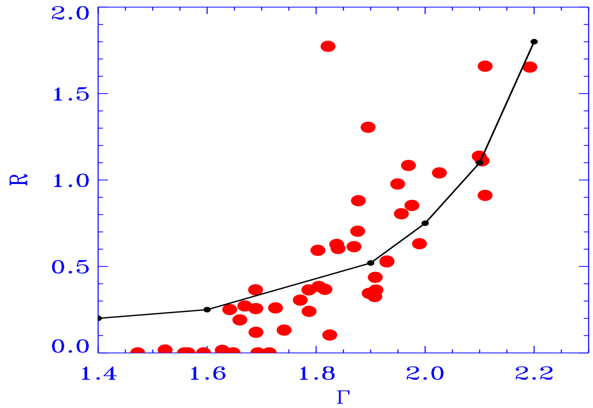

Figure 1. The R–Γ correlation obtained assuming a primary powerlaw spectrum with a varying photon index, at constant 0.01-100 keV luminosity and a fixed reflected flux (solid line; see text). The simulated spectra were fitted using PEXRAV in the 2-30 keV range. The circles show the *Ginga*data of Zdziarski *et al.*1999. The errors are omitted.

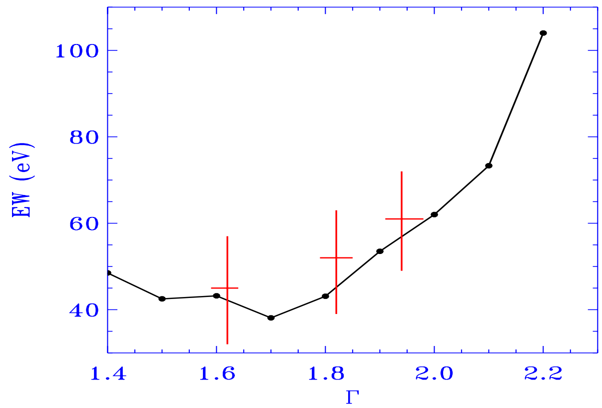

Figure 2. The iron line equivalent width as a function of Γ assuming a primary Comptonised spectrum with a varying photon index a constant 0.01-100 keV luminosity and a fixed line flux (solid line; see text). The crosses show the data for the three averaged spectra of Lubiñski & Zdziarski (2000)

spectrum is hard the observed primary flux in the 10–30 keV band is larger, and R is reduced, on the other hand when the spectrum is soft the primary flux in this energy range is enhanced and R is lower. It thus produces *a positive correlation between R and Γ*. Fig. 1 shows that *the produced correlation qualitatively match the observed R-Γ correlation observed in the sample of Gingadata from Zdziarski et al.1999.* Note that a spectral pivot above 10-20 keV would produce the an anti-correlation.

6.2. The iron line equivalent width vs Γ relation

Fluctuations of the primary continuum do affect the measured EW. The resulting dependence of the measured equivalent width with Γ is plotted on Fig 2. The EW represents the amount of reflection at 6.4 keV i.e. at a lower energy than the reflection bump. The correlation obtained for EW is weaker than for R (actually we even get an anti-correlation at low Γ).

Using a large ASCA sample, Lubiński & Zdziardski (2000) produced 3 average spectra of Seyfert 1s grouped according to increasing spectral index. For each spectra they could detect a narrow Fe line component that they attribute to reflection on a torus. *Their estimates for the narrow line EW appear to be consistent with the results from our modeling* as show in Fig 2.

7. Conclusion

We showed that the effect of the remote cold material may in principle account simultaneously for the observed correlation between the R and Γ, and the observed narrow line component which is almost independent of Γ. It should be stressed however, that the comparisons of our model with the R-Γ correlation observed in a *s*ample of sources, implicitly assumes that all the sources present a similar variability mode (i.e. variability at constant flux), time average properties as well as geometry of the DCM. This is probably oversimplifying (as suggested by the spread of the data points in the R-Γ plane). In particular in several sources a correlation between the 2–10 keV flux and spectral slope is reported (e.g. Chiang *et al.*2000), while our variability assumptions lead to an anti-correlation. Concerning the R-Γ correlation we implicitly assumed that the reflection on inner cold material (e.g. disc reflection) is negligible in all sources. This is probably not the case since the observed iron lines also present a broad component which is unlikely to be produced far away from the central engine.

Given these uncertainties, we conclude that beside the extreme DCM dominated case considered here for illustration, *reflection arising from the DCM could be important in many sources*, making any attempt to constrain the physical properties and the geometry of the central engine with reflection measurements very difficult.

REFERENCES

1. Antonucci, R. R., 1993, ARA&A, 31, 473.
2. Beloborodov, A. M., 1999, MNRAS, 305, 181.
3. Chiang J. *et al.*, 2000, ApJ, 528, 292.
4. George, I., & Fabian, A. C., 1991, MNRAS, 249,352.
5. Ghisellini, G., Haardt, F., & Matt, G., 1994, MNRAS, 267, 743.
6. Matt, G., Fabian, A.C., Guainazzi, M., Iwasawa, K., Bassani L., & Malaguti, G., 2000, MNRAS, 318, 173.
7. Haardt, F., & Maraschi, L., 1993, ApJ, 413, 507.
8. Krolik, J.H, Madau, P., & Życki, P. T., 1994, ApJ, 420, L57.
9. Lubiñski, P., & Zdziarski, A. A., 2001, MNRAS, 323, L37.
10. Malaguti, G., *et al.*, 1998, A&A, 331, 519.
11. Magdziarz, P., & Zdziarski, A. A., 1995, MNRAS, 273, 837.
12. Malzac, J., & Jourdain, E., 2000, A&A, 359, 843.
13. Malzac, J., Beloborodov A.M., Poutanen J., 2001, MNRAS, 326, 417.
14. Nandra, P., *et al.*, 2000, ApJ, 544, 734.
15. Nicastro, F., *et al.*, 2000, ApJ, 536, 718.
16. Petrucci, P.O., *et al.*2000, ApJ, 540, 131.
17. Reynold, C.S., Fabian A.C., Makishima K., Fukasawa Y., Tamura T., 1994, MNRAS, 268, L55
18. Uttley, P., *et al.*, 1999, MNRAS, 307, L6.
19. Zdziarski, A. A., Lubiński, P., Smith, D. A., 1999, MNRAS, 303, L11.

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